Ask Dr. ALOHA:

Why the 10-kilometer and 1-hour limits?

Jane Smith was preparing a report for Central City's emergency management department describing the possible effects of accidental hazardous chemical releases from the Central City Water Treatment Plant and nearby Central City Chemical Company. She had used ALOHA to run a variety of accident scenarios. But she had encountered an obstacle. The city planners for whom she was working wanted to see only exact numbers in her report. ALOHA, though, insisted on telling her that the footprint length (the downwind distance to her level of concern, or LOC) for some of her scenario runs was "greater than 6 miles," (10 kilometers) and that for a few of her scenarios, "ALOHA limited the duration to 1 hour." She knew that these results from ALOHA weren't specific enough to satisfy the Central City managers.

What to do? Jane called CAMEO Technical Support to ask: isn't there some way to get around the limits that ALOHA places on its output? But she was told that there is not. Have you ever found yourself in Jane's position? Let's examine why ALOHA places limits on both release duration and footprint length.

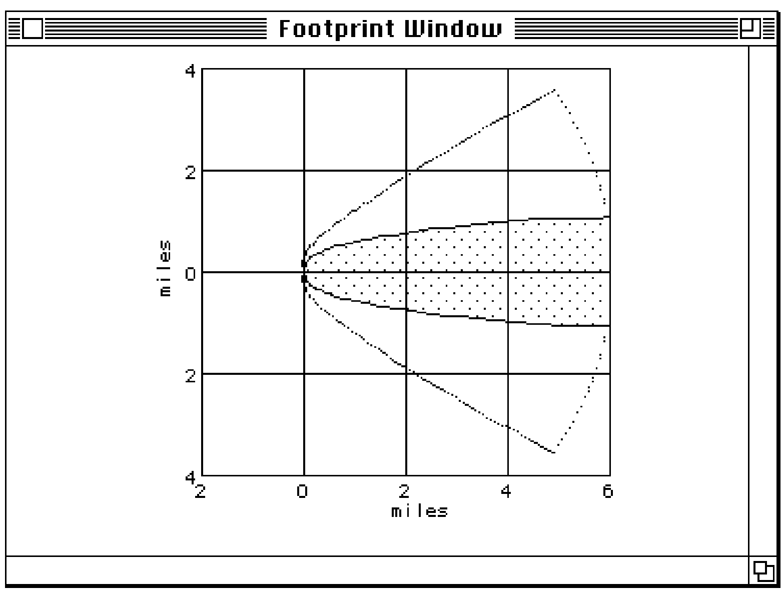

Figure 1. An ALOHA footprint that is greater than 6 miles (10 kilometers) in length, truncated 6 miles downwind of the release point.

The atmosphere is turbulent

Meteorologists call the atmosphere a turbulent fluid (to scientists, a fluid can be a gas or a liquid). Just as in a stream or river, this turbulence is manifested in eddies of all sizes. Eddies in the atmosphere can range in size from a fraction of an inch to a few miles across. The degree of atmospheric turbulence is a major factor in determining how quickly a pollutant cloud, as it moves downwind, will mix with the air around it and be diluted below your LOC. How quickly a cloud will be diluted to below the LOC affects the size of its footprint, as plotted by ALOHA (remember that an ALOHA footprint encompasses the area where the model expects your LOC, at ground level, to be reached or exceeded).

For a model like ALOHA to predict accurately how a pollutant will disperse, it must be able to estimate the degree of turbulence in the atmosphere. To do this, a model must incorporate any of several methods called *turbulence typing schemes*.

ALOHA's turbulence typing scheme

ALOHA uses a turbulence typing scheme developed by F. Pasquill and later modified by F. A. Gifford. Pasquill and Gifford knew that unless an inversion exists, air temperature declines as elevation increases. If temperature declines rapidly with elevation, warmer air near the surface will tend to move upwards a long distance before it cools to the temperature of the air around it and ceases to rise. Under such conditions, the atmosphere is considered "unstable," or relatively turbulent. The strong tendency of warmer air near the surface to rise causes substantial convection (vertical mixing of air). As warm air rises, it displaces cooler air above it, which then sinks downwards. This convection generates relatively many, large eddies. Unstable conditions are associated with moderate to strong incoming solar radiation. According to the Pasquill-Gifford typing scheme, the atmospheric stability class would be A or B.

If on the other hand temperature declines only slowly with elevation, warmer air near the surface will tend to move upwards only a short distance. Less upward convection will cause fewer, smaller eddies to form. In this case, the atmosphere is considered "stable,", or less turbulent, and the stability class would be E or F. Stable conditions are associated with relatively low wind speeds and low solar radiation. Stability classes D and C represent conditions of more neutral stability, or moderate turbulence. Neutral conditions are associated with relatively strong wind speeds and moderate solar radiation.

You may know from your experiences using ALOHA that your choice of stability class has a big effect on the model's prediction of footprint size. Under unstable conditions, for example, a dispersing gas will mix rapidly with the air around it. ALOHA will expect the cloud to extend less far downwind than it would under more stable conditions, because the pollutant will soon be diluted below your LOC.

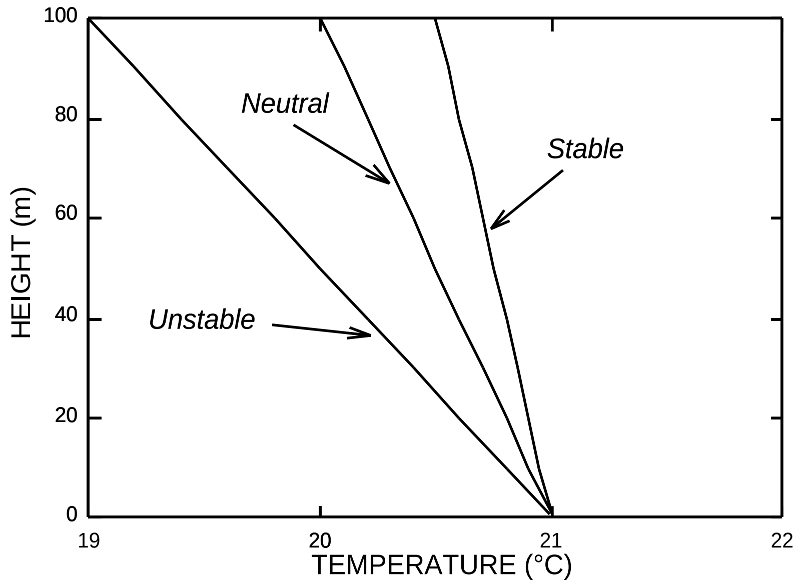

Figure 2. Change in air temperature with height above the ground, under example unstable, neutral, and stable atmospheric conditions.

Ground roughness also creates turbulence

Friction between the ground and air passing over it also creates turbulence. Because the air nearest the ground is slowed the most, eddies develop, just as they would in the water next to a riverbank. The rougher the ground surface, the greater the degree of turbulence that develops. These friction-generated eddies are usually smaller than those generated by upward convection, but they act in the same way to dilute a pollutant cloud by mixing it with the air around it. You may have found that your choice of ground roughness is an important influence on ALOHA footprint size: when all other inputs are equal, a footprint will be smaller when you choose a larger ground roughness value (such as “Urban or forest”).

Estimating the dimensions of a plume

G. Briggs developed a set of *dispersion coefficients* for each of the Pasquill-Gifford stability classes, and for both urban (high roughness, much turbulence) and rural (low roughness, low turbulence) ground roughness conditions. (ALOHA calls these two roughness categories “Urban or forest” and “Open country.”) For each combination of ground roughness and atmospheric stability class, his coefficients describe mathematically how atmospheric turbulence affects the size of a dispersing pollutant cloud. When a pollutant cloud is about as bouyant as air, ALOHA uses Briggs’ coefficients to estimate its dimensions. (ALOHA relies on the Pasquill-Gifford scheme, but not on Briggs’ coefficients, when it estimates the dimensions of a cloud of heavier-than-air gas.)

Some experiments

The Pasquill-Gifford typing scheme and Briggs' coefficients are *empirical*. That is, they are based on the results of actual experiments, rather than on pure theory. To understand why the limits on ALOHA's output exist, we can look at Project Prairie Grass, the most extensive and important of the experiments which form the basis of Pasquill's, Gifford's, and Briggs' work.

Project Prairie Grass was conducted during the summer of 1956 in flat, open prairie country in northcentral Nebraska. During each of the 70 Prairie Grass trials, researchers released sulfur dioxide continuously for a 10-minute period. As each gas cloud moved downwind, the amount of sulfur dioxide in the cloud was measured by sensors located along arcs from 50 to 800 meters downwind of the point of release. Researchers used the observations from this and similar experiments to see how quickly a gas cloud spreads outwards under different atmospheric stability classes. Pasquill, Gifford, Briggs, and others then developed equations to describe this spreading; these are included in ALOHA and other models.

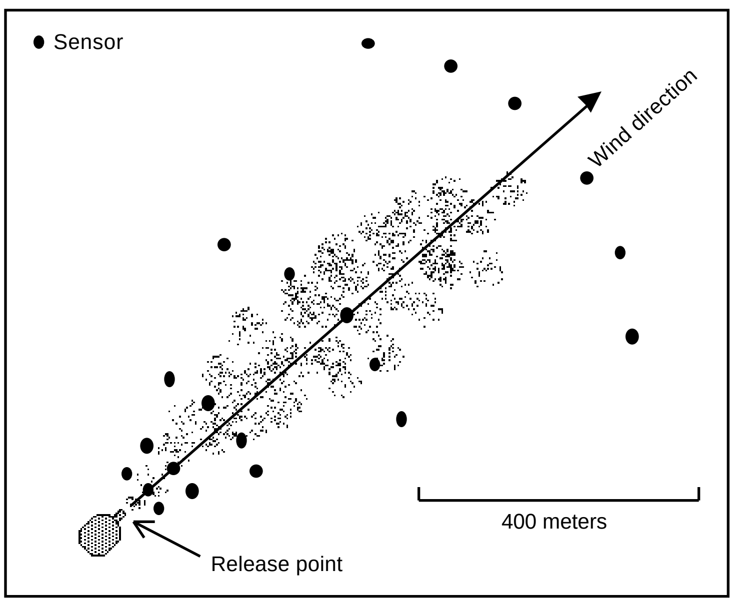

Figure 3. Diagrammatic view of a sulfur dioxide release during Project Prairie Grass. No sensors were placed further than 800 meters (0.8 kilometers) from the release point.

During the experiments on which this work was based, including Project Prairie Grass, most concentration measurements were made at distances within 1 kilometer (0.6 mile) from the release point. In only a few instances were concentrations measured at distances as far as 10 kilometers (6 miles) from the release location. This means that we can't be sure that the dispersion estimation methods used by ALOHA and other air models would be accurate farther from the source. Researchers generally recommend that these methods should be used to calculate concentration only for locations no more than about 10 kilometers (6 miles) downwind from the release point.

Likewise, during each of the Project Prairie Grass experiments sulfur dioxide was released for a period of 10 minutes. The Pasquill-Gifford stability classes are based only on this and other experiments with 10-minute releases. When Briggs developed his dispersion coefficients, he also used results from two other experiments, in which some releases of up to 1 hour were made. Hence, his dispersion coefficients are based on experimental releases ranging from 10 minutes to 1 hour in duration. Researchers generally recommend that the Pasquill-Gifford and Briggs estimation methods should be used to calculate concentration only for releases of, at most, 1 hour in duration.

Other reasons for the time and distance limits

There are other reasons for imposing the time and distance limits on ALOHA's output. One reason for ALOHA's 1-hour time cutoff is that the wind shifts direction and changes speed frequently. If ALOHA has incorrect values for wind speed and direction, it can't correctly estimate footprint size or location. Placing a 1-hour cutoff on ALOHA's predictions helps to ensure that you won't inadvertently use invalid ALOHA predictions a couple of hours after a spill has begun, when conditions have changed from those that you originally entered into the model.

Another reason for the 10-kilometer cutoff for ALOHA footprint length is that we don't know what the wind speed and direction are 10 kilometers away, and can't assume that they are the same as those we're experiencing at the point where a pollutant is being released. Terrain effects, such as channeling along a river valley or around hills and slopes, cause the wind to change both speed and direction, and can even cause the wind to reverse direction completely.

Finally, ALOHA expects the terrain beneath a moving pollutant cloud to be flat and free of large obstacles; but in few places is that the case for distances as great as 10 kilometers.

Where does this leave Jane?

Jane needs to remind the Central City planners that the output from a model such as ALOHA is intended to be a best guess, never to be confused with actual fact. By placing limits on its output, ALOHA is trying to remind you of its own limitations. Although release durations "limited to 1 hour" or footprint lengths "greater than 6 miles" do not fit as neatly into tables and reports as precise numbers do, they exist to remind you that, for a particular scenario, an actual number could be wrong.

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